Conference Paper

The Petrophytic Steppes of the Urals: Diversity and Ecological Drivers

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Abstract

The diversity and main compositional patterns of the petrophytic steppes of the Urals were studied. Two questions were considered in detail: (i) How rich is the phytocoenotic diversity of the petrophytic steppes? and (ii) What kind of ecological drivers determine its differentiation? A dataset of 1,025 relevés was compiled, representing communities of different climatic and geological conditions. Using formalized classification (TWINSPAN algorithm), eight vegetation types on the petrophytic steppes were defined. DCA-ordination was used to determine the main ecological drivers (both climatic and edaphic) of plant communities' diversity. Among them are mean annual temperature and precipitation, aridity, rockiness and local habitat moisture. The interaction of different ecological and geographical factors leads to high levels of floristic and coenotic diversity of vegetation in dry rocky habitats.

Keywords: petrophytic steppes, ecological drivers, ordination, Southern Urals

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1. Introduction

Steppe ecosystems are among the most endangered in the world [1, 2]. The long-term human impact has led to a total degradation of steppe vegetation in Eurasia. Steppe communities remain only in habitats unsuitable for plowing, including stony habitats with coarse soils. The Southern Urals is one of the regions where stony habitats are widespread, and they hold a variety of steppe flora and vegetation [3, 4].

Conducting studies on petrophytic vegetation is an urgent task. For certain regions of Europe and Asia, data on the variety and organization of steppes with stony habitats have been obtained [5–9], including the Ural region [4, 10, 11].

Petrophytic steppes have a high level of floristic and phytocoenotic diversity. Numerous rare and endangered plants, including relict and endemic species, grow in dry grasslands on stony habitats. At the same time, there is a significant gap in our knowledge of plant communities' diversity and the ecological relationships within petrophytic vegetation of the Urals. During the last decade, many specific studies concerning stony steppe habitats in different regions of the Southern and Central Urals were carried out by the authors of this work.

The authors set the objective to investigate the diversity and patterns of the organization of petrophytic steppe communities. We have pointed out the following tasks: to describe the phytocoenotic variety of the petrophytic steppes of the Urals and to define the ecological drivers determining their differentiation.

2. Methods

The studied area is located in the Central and Southern Urals and covers mainly steppe and forest steppe regions. There is a boundary between the East European and West Siberian plains in the Ural Mountains. The climate of the region is temperately continental. The average annual air temperature varies from 0.3–0.9°C to 3.1–3.9°C, while the average annual precipitation varies from 577 to 400 mm. Climatic features are strongly influenced by the arrangement and absolute height of the Ural ridges. Vegetation is structured in terms of zonal types replacing each other: from taiga forest in the north to typical dry steppes in the south. The latitudinal range of the studied steppes distribution covers more than 900 km. In the plain areas of the Cis-Urals and Trans-Urals, the soils change from gray forest type to chernozems (leached, ordinary, and southern chernozems and, less frequently, solonetzic and solonchak chernozems). The soil cover of low ranges and ridges is dominated by coarse and eroded soils with frequent rock exposures.

There is a wide range of different bedrock types influencing steppe community composition. Exposures of carbonates and gypsum are widespread in the Cis-Ural region. There are no gypsum rocks in the Trans-Ural region: carbonates are rare and metamorphic bedrocks prevail. In the Central Urals, the sites of petrophytic steppes are confined to the main and ultra-basic bedrocks (limestones, dunites, pyroxenites, etc.).

The elaborated dataset consists of 1,025 relevés included in the South Ural non-forest vegetation database (GIVD ID 00-RU-006), and also contains additional data collected by the authors. The relevés were made for 100-m^2 plots using a standard procedure or, in some cases, within the natural borders of communities. All relevés were classified using the TWINSPAN algorithm in JUICE 7.0 [12]. The number of division levels was set to 4, resulting in 16 clusters. After analyzing the floristic composition and geographical distribution of each cluster, we merged adjacent clusters with no obvious differences in species composition and with a similar position along the ecological and geographical gradients. To determine the main drivers of petrophytic steppe diversity, DCA-ordination in the Canoco 4.5 software package was used [13]. To characterize ecological features of habitats, the soil moisture statuses were calculated using the Ramensky scale [14]: bioclimatic parameters values were determined.

3. Results

According to the TWINSPAN results, the dataset was divided into 8 groups of relevés. They reveal ecological and geographical plant communities characterized by differential species.

(i) petrophytic steppes on chalks, gypsum, limestones, sandstones and marl located in the southern part of the Cis-Ural region. They are indicated by dry steppe species (*Stipa lessingiana, Kochia prostrata, Meniocus linifolius, Artemisia lerchiana, Stipa sareptana*) and petrophytes (*Centaurea carbonata, Hedysarum razoumovianum, Artemisia salsoloides, Gypsophila patrinii* s.l., *Orostachys thyrsiflora, Sterigmostemum tomentosum, Anthemis trotzkiana* etc.).

(ii) petrophytic steppes of the Trans-Ural region located on metamorphic rocks (granites, jaspers, ultrabasites). They are differentiated by typical steppe species (*Spiraea hypericifolia, Silene wolgensis* s.l., *Androsace maxima, Ferula tatarica, Veronica incana*) and petrophytes including, Ural endemic species (*Thymus guberlinensis, Elytrigia pruinifera, Linaria uralense, Dianthus uralensis*).

(iii) petrophytic steppes of the Cis-Ural region located mainly on limestones exposures within the forest-steppe zone and the northern part of steppe zone. Differential species: *Hedysarum grandiflorum, Agropyron pectinatum, Centaurea marschalliana, Stipa korshinskyi*.

(iv) hyperpetrophytic steppes of the Trans-Ural forest-steppe zone and the Cis-Ural residual reef-origin mountains. Ural endemic petrophytic species prevail in a diagnostic combination: *Dianthus acicularis, Asperula petraea, Minuartia krascheninnikovii, Astragalus karelinianus, Tanacetum uralense, Oxytropis gmelini*.

(v) petrophytic variants of the relict steppes of the Urals Mountains. Light coniferous forest species are common for this group (e. g. *Aconogonon alpinum*). The presence of typical steppe species (e.g., *Poa transbaicalica*) is also common. This indicates the relict origins of the studied communities. There are petrophytes in the diagnosis (*Sedum hybridum, Eremogone saxatilis*, etc.).

(vi) petrophytic variants of the meadow steppes of the southern part of the forest-steppe zone in the Cis-Ural region. They are mainly distributed on limestone. The diagnostic species group includes both xeromesophytes (*Astragalus austriacus, Stipa pulcherrima, Astragalus onobrychis, Anemone sylvestris, Scabiosa ochroleuca*, etc.) and thermophytic forest edge species (*Agrimonia asiatica, Hypericum elegans*).

(vii) petrophytic variants of the meadow steppes of the forest-steppe zone in the Trans-Ural region. The diagnostic species group is rather heterogeneous. It includes species of light coniferous forests (*Brachypodium pinnatum, Dracocephalum ruyschiana, Calamagrostis arundinacea* etc.), dry meadows (*Ranunculus polyanthemos, Rumex thyrsiflorus, Sanguisorba officinalis* etc.) and meadow steppes (*Phlomoides tuberosa, Thymus marschallianus, Centaurea scabiosa*).

(viii) northern variant of the petrophytic steppes of the Central Urals taiga-forest belt. This type is close to the previous ones and is differentiated by the presence of *Pinus sylvestris* seedlings and an increase in meadow species (*Plantago media, Rumex acetosella, Galium album*). There are also *Pulsatilla uralensis, Silene klokovii* and the Ural endemic *Thymus hirticaulis* in the diagnosis.

Thus, petrophytic steppes are characterized by great diversity and are distributed in different regions and altitudinal belts on different bedrocks. The DCA-ordination (Figure 1) diagram illustrates the main ecological patterns. The first axis reveals local habitat moisture and the gradient of mean annual temperature: these vectors are diametrically opposed. There is a gradual replacement of the southern variants of petrophytic steppes in the steppe zone by mountain-taiga belt communities on this axis. The second axis reveals rockiness and mean annual precipitation. It is interesting that local habitat moisture and mean annual precipitation are correlated with different axes. This is a characteristic feature of azonal petrophytic steppes and distinguishes them from zonal types with synchronous changes in precipitation and local habitat moisture. Prevailing geological bedrocks, clearly different in the Cis-Urals and Trans-Urals regions, make an important contribution to the differentiation of communities along the second axis.

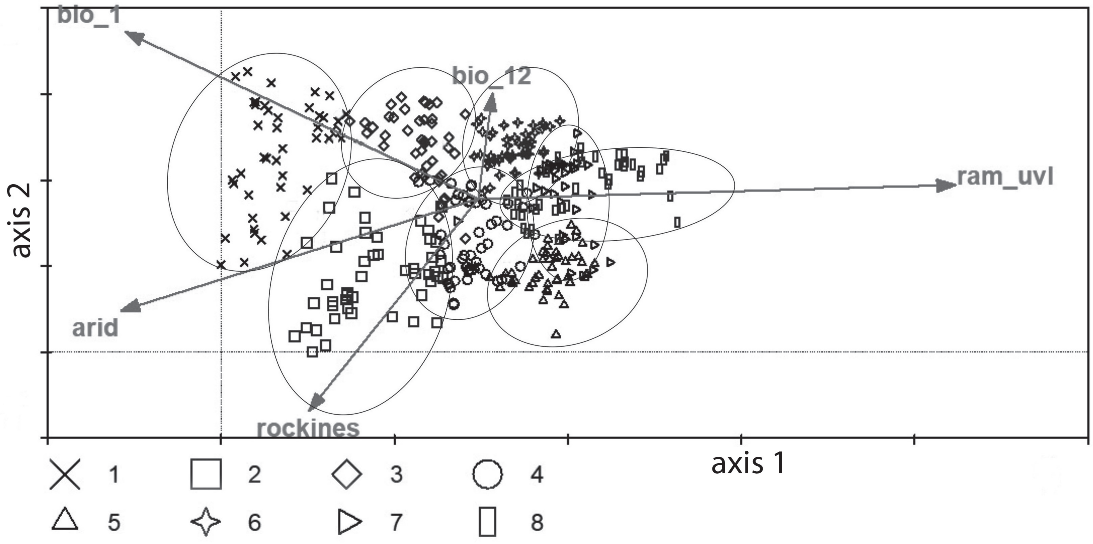

Figure 1: DCA-ordination of the petrophytic steppes of the Urals: 1–8 – communities. Ecological factors: bio1 – mean annual temperature, bio 12 – mean annual precipitation, arid – Thornthwaite aridity index, rockiness – degree of substratum stoniness, ram_uvl – local habitat moisture. **Source:** Authors' own work.

The petrophytic steppes of the Urals can be considered as one type of vegetation. This is confirmed by shared species group, typical for all the defined types of communities. The species of this group are very widely distributed over the steppe of the studied region: *Festuca valesiaca* s.l., *Stipa pennata, Campanula sibirica, Veronica spicata, Filipendula vulgaris, Thalictrum minus, Seseli libanotis*, etc. Obligate and facultative petrophytes are common: *Centaurea sibirica, Echinops ritro* s.l., *Allium rubens, Artemisia commutata, Tanacetum kittaryanum, Euphorbia seguierana*, etc.

The distribution of the first four community types is connected with the steppe and the southern part of the forest-steppe zones. They are characterized by the presence of obligate petrophytes (*Astragalus helmii, Orostachys spinosa, Hedysarum argirophyllum*, etc.) and xerophytes and mesoxerophytes (*Poa crispa, Ephedra distachya, Potentilla glaucescens*, etc.). Communities of types 5–8 are more mesic. This is indicated by the high level of activity of mesophytes (*Achillea millefolium, Pimpinella saxifraga, Vicia craca*, etc.) and xeromesophytes (*Amoria montana, Fragaria viridis, Inula hirta*, etc.)

4. Conclusion

Various ecological gradients have an influence on the differentiation of the petrophytic steppes of the Urals. High floristic diversity and the presence of stenotopic endemic plants are characteristics of a great diversity of plant communities. At the same time, there are groups of species indicating confinement to the steppes on various belts or their phidelity to certain rocks. These features of petrophytic steppe vegetation have to be considered in classification schemes. They are also important for developing a biodiversity conservation strategy for the Urals. Many types of the described communities are rare by themselves: they are also habitats of rare, relict and endemic plant species.

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References

[1] Török, P., Ambarli, D., Kamp, J., et al. (2016). Step(pe) up! Raising the profile of the Palaearctic natural, grasslands. *Biodiversity Conservation*, no. 25, pp. 2187–2195.

[2] Wesche, K., Ambarli, D., Kamp, J., at al. (2016). The Palaearctic steppe biome: A new synthesis. *Biodiversity Conservation*, no. 25, pp. 2197–2231.

[3] Knyazev, M. S., Mamaev, S. A., and Vlasenko, V. E. (2007). Relict communities and populations of petrophilous plant species in northern regions of Sverdlovsk Oblast and problems in their conservation. *Russian Journal of Ecology*, vol. 38, no. 5, pp. 317–322.

[4] Yamalov, S. M., Bayanov, A. V., Martynenko, V. B., et al. (2011). Endemic associations of the petrophytic steppes of the South Ural Palaeoreefs. *Vegetation of Russia,* vol. 19, pp. 117–126.

[5] Poluyanov, A. V. (2009). Petrophytic feather-grass and thyme steppes in the southeast of the Kursk Region (within the limit of the Oskol River Basin). *Vegetation of Russia,* vol. 14, pp. 49–62.

[6] Korolyuk, A. Yu. and Makunina, N. I. (2009). True steppes of the Altai-Sayan Mountain area (order *Stipetalia krylovii* Kononov, Gogoleva et Mironova 1985). *Plant Life of Asian Russia,* vol. 2, pp. 43–53.

[7] Janišová, M. and Dúbravková, D. (2010). Formalized classification of rocky Pannonian grasslands and dealpine Sesleria-dominated grasslands in Slovakia using a hierarchical expert system. *Phytocoenologia*, vol. 40, no. 4, pp. 267–291.

[8] Dúbravková, D., Chytry, M., Willner, W., et al. (2010). Dry grasslands in the western Carpathians and the northern Pannonian Basin: A numerical classification. *Preslia*, no. 82, pp. 165–221.

[9] Polyakova, M. A. (2016). Trends in the formation of cenotic diversity of steppe vegetation in mountain steppe landscapes of Khakassia. *Russian Journal of Ecology,* vol. 47, no. 2, pp. 207–210.

[10] Gorchakovskii, P. L. and Zolotareva, N. V. (2006). Phytodiversity of relict steppe enclaves in the Urals: Experience in comparative assessment. *Russian Journal of Ecology*, vol. 37, no. 6, pp. 378–386.

[11] Lebedeva, M. V., Yamalov, S. M., and Korolyuk, A. Yu. (2017). Ecological cenotic groups of species in the Bashkir trans-Ural steppes in relation to key ecological factors. *Contemporary Problems of Ecology*, vol. 10, no. 5, pp. 455–463.

[12] Tichý, L. (2002). JUICE, Software for Vegetation Classification. *Journal of Vegetation Science*, vol. 13, pp. 451–453.

[13] Ter Braak, C. J. F. and Šmilauer, P. (2002). *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5)*. Ithaca: Microcomputer Power.

[14] Ramensky, L. G., Tcatcenkin, I. A., Chijikov, O. N., et al. (1956). *Ecological Assessment of Forage Land According Plant Cover*. Moscow: Sel'khozgiz.